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PERCEIVED TIME PROGRESSION AND VIGILANCE: IMPLICATIONS FOR WORKLOAD, STRESS, AND CEREBRAL HEMODYNAMICS

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14. ABSTRACT
This study tested the possibility that the temporal context in which a vigilance task is performed will moderate the perceived workload and stress of the task. We employed a procedure to manipulate participants' perceived time progression (PTP) during task performance by creating a mismatch between their expectations about how long they would perform the task and the actual time they were engaged (Sackett et al., 2010). All participants completed two 30-minute vigilance task sessions, separated by a 15-minute rest period. Those in a time drags condition were led to believe each session would last 15 minutes while those in a time flies condition were told each would last 60 minutes. A control group was informed of the true length of the vigil with no attempt to manipulate PTP. PTP was significantly slower in the time drags and control conditions compared to the time flies condition. However, measures of performance (perceptual sensitivity and response bias), workload scores on the NASA Task Load Index, stress scores on the Dundee Stress State Questionnaire, and cerebral hemovelocity scores were similar in all conditions. Evidently, vigilance tasks are perceived as hard work even when time flies.

15. SUBJECT TERMS
vigilance, cerebral hemovelocity, transcranial Doppler sonography, perceived time progression, stress, workload

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1.0 INTRODUCTION

Vigilance or sustained attention tasks require observers to maintain their focus of attention and to detect infrequent and unpredictable targets over prolonged periods of time (Davies & Parasuraman, 1982; Hancock, 2013; Warm, 1984). These assignments are of interest to the Air Force because of the vital role that vigilance occupies in automated human-machine systems (Adams, 1987; Craig, 1984; Davies & Parasuraman, 1982; Howell, 1993). Advancements in technology have shifted human involvement in such systems from active control to supervisory control wherein operators monitor the functions of the systems and intervene only in the case of system malfunction or when system diagnostics indicate the need for immediate action (Sheridan, 1970, 1980). Consequently, vigilance has a critical impact in a wide range of automated systems in Air Force-related areas such as air-traffic and flight control, airport/border security, and enemy surveillance. Signal detection failures in these situations and in non-military operational settings as well have led to unfortunate consequences (Baker, 1962; Colquhoun, 1967, 1977; Pigeau, Angus, O'Neill, & Mack, 1995; Schmidke, 1976;Warm, Parasuraman, & Matthews, 2008). Thus, it is important to understand as much as we can about the dynamics of the operator's experience during the performance of vigilance tasks (Vidulich, Wickens, Tsang, & Flach, 2010; Warm, Parasuraman, et al., 2008; Wickens, Hollands, Banbury, & Parasuraman, 2013).

The quintessential finding in vigilance research is the decline in performance over time, or the vigilance decrement, which has been found in a wide array of experiments (Davies & Parasuraman, 1982; Matthews, Davies, Westerman, & Stammers, 2000; See, Howe, Warm, & Dember, 1995; Warm, Parasuraman, et al., 2008). Concordant with the vigilance decrement is the traditional view that vigilance tasks are tedious but benign assignments that place little demand upon operators (Frankman & Adams, 1962; Heilman, 1995; Nachreiner & Hanecke, 1996). These assignments were thought to induce the vigilance decrement due to a decline in arousal resulting from their understimulating nature. It was thought that the repetition and monotony of vigilance tasks reduces activity within brain systems (the locus coeruleus and the reticular activating system) needed for continued alertness. Consequently, lethargy increases in observers and signal detection is reduced. However, recent findings indicate that while they are tedious, vigilance tasks impose substantial demand upon the information-processing resources of participants and are highly stressful (Warm, Parasuraman, et al., 2008). This more recent view has emerged from studies examining (1) perceived mental workload, (2) task-induced stress, and (3) neural measures of resource demand as indexed by cerebral hemovelocity. Such findings have led resource theory to be viewed as a dominant model in the study of vigilance performance (Johnson & Proctor, 2004; Langner, Eickhoff, & Steinborn, 2011; MacLean et al., 2009; Smit, Eling, & Coenen, 2004; Parasuraman, 1979; Parasuraman, Warm, & Dember, 1987; Warm & Dember, 1998; Warm, Parasuraman, et al., 2008; Proctor & Vu, 2010; Wiggings, 2011). Since vigilance tasks, like human activities in general, are performed within a perceived temporal framework, the present study addressed the effects of that framework upon task-induced workload, stress, and cerebral hemodynamic changes associated with task performance.

1.1. Information Processing Demand of Vigilance

Much of the evidence of high information processing demand comes from studies using the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), a widely used subjective workload measure considered to be one of the most effective means of quantifying perceived mental workload (Wickens et al., 2013). The NASA-TLX provides a reliable measure of overall or global workload on a scale from 0 to 100, and it identifies the contributions of six sources of workload: Mental Demand, Temporal Demand, Physical Demand, Performance, Effort, and Frustration (Nygren, 1991). Vigilance studies employing the NASA-TLX indicate that global scores in these types of tasks typically fall within the upper level of the scale and exceed those characteristic of other tasks such as memory search, choice reaction time, mental arithmetic, and grammatical reasoning (Warm, Dember, & Hancock, 1996; Warm, Matthews, & Finomore, 2008; Warm, Parasuraman, et al., 2008).

A key element in regard to workload is the identification of the factors that influence its subjective evaluation (Liu & Wickens, 1994). Task difficulty is an immediate consideration as an element influencing workload, and in regard to vigilance, the NASA-TLX has been found to discriminate among experimentally imposed differences in levels of difficulty (Warm et al., 1996; Warm, Matthews, et al., 2008; Warm, Parasuraman, et al., 2008). Along this line it is noteworthy that the passage of time is related to task demand (Block, Hancock, & Zakay, 2010), and several studies outside the vigilance area have used perceived duration as a workload index. These studies have shown that verbal estimates of perceived task duration vary inversely with task demand (Block et al., 2010; Carswell, Clarke, & Seales, 2005; Hart, 1975; Fortin & Rousseau, 1987; Zakay & Shub, 1998). To date, perceived duration has not been examined in regard to the workload of vigilance tasks, but it is possible that the temporal framework in which a vigilance task is performed will affect the perceived workload of that task. More specifically, Sackett and his associates (2010) have developed a procedure to manipulate participants' perceived time progression (PTP) during task performance. In these studies participants were asked to engage in a number of mundane tasks (e.g., reading text, listening to irritating sounds, listening to music). To influence PTP, the investigators created a mismatch between participants' expectations about how long they would be performing a task and the actual time they performed. All participants performed the task for an identical period of time. However, in a *time flies* condition they were told that they would be working for a longer duration than they actually did and in a *time drags* condition they were told that they would work for a shorter duration than they actually did. Sackett and his colleagues found that upon task completion, participants in the *time flies* condition rated time as having passed more quickly than did those in the *time drags* condition and rated the task to be more enjoyable. In the authors' words, "You are having fun when time flies." With this in mind, it is conceivable that increasing participants' PTP in the performance of a vigilance task (*time flies* condition) will lower perceived workload in relation to the case in which participants' PTP is decreased (*time drags* condition). The present study represents the initial experimental effort to extend the findings of Sackett et al. (2010) to vigilance, and thereby determine if the temporal context is a moderator variable for the subjective evaluation of workload in vigilance performance.

1.2. Evaluation of Stress

Given the mounting evidence that stress plays a role in lowering worker health, safety, and productivity (Miller, Chen, & Zhou, 2007; Nickerson, 1992), the workload/stress induced by the performance of vigilance tasks is a concern for Air Force personnel. Consequently, a second goal for the present study was to examine the relation between the temporal context and the stress associated with performing a vigilance task.

Hancock and Szalma (2008) have identified a central theme that characterizes modern approaches to stress and performance in the appraisal mechanism by which individuals evaluate environmental events, including the tasks that confront them, in terms of their physical and psychological well-being and their ability to cope with those events (Lazarus & Folkman, 1984; Hancock & Warm, 1989; Matthews, 2001; Matthews & Campbell, 1998; Salas, Driskell, & Hughes, 1996). In line with this assertion, stress is defined as a transaction between the individual and an environment in which the individual views the demand of the environment as taxing his or her resources or endangering his or her well-being (Lazarus & Folkman, 1984). As Warm, Matthews, et al. (2008) have pointed out, the transactional model of stress implies a bidirectional relation between stress and task performance. The pressures imposed by the task elicit physiological and subjective stress responses which in turn, feedback to influence information-processing and the individual's strategies for coping with task demands.

Several physiological measures have been employed as indices of the stress induced in observers by vigilance tasks. These include elevated amounts of circulating catecholamines (Asteria, 1985; Dunbar, 1954; Parasuraman, 1984; Wesnes & Warburton, 1983) and elevated levels epinephrine, norepinephrine, and cortisol (Frankenhaeuser, Nordheden, Myrsten, & Post, 1971; Frankenhaeuser & Patki, 1964; Lundberg & Frankenhaeuser, 1980). In addition, studies using electromyographic techniques and measures of physiological tremor have found increased levels of muscle tension in observers during a vigil (Carriero, 1977; Hovanitz, Chin, & Warm, 1989) and increasing restlessness and muscle tremor as time on task progresses (Galinsky, Rosa, Warm, & Dember, 1993; Thackray, Bailey, & Touchstone, 1977). Vigilance tasks have also been found to induce tension headaches in sensitive observers (Hovanitz et al., 1989).

Along with physiological measures, self-report measures have also been utilized to gauge the level of stress induced during the performance of a vigilance task. While these measures are correlated with the physiological markers, the correlations are not as robust as might be expected if the different measures tap the same phenomenon (Matthews, 2001). Thayer (1989) has pointed out that self-report measures are more closely coupled with cognitive states than physiological measures and therefore might provide greater insight into the nature of the psychological processes underlying stress. Accordingly, the present study employed self-report measures of stress surrounding a vigilance assignment.

1.2.1. Dundee Stress State Questionnaire

As described in an extensive review by Warm, Matthews, et al. (2008), several self-report studies of the stress of vigilance have found that observers rate themselves as feeling less attentive and

more bored, strained, irritated and fatigued after a vigil than prior to its start and that vigilance tasks induce feelings of sleepiness and fatigue. However, the reviewers note that these initial self-report indices are limited because the scales involved appear to have been chosen arbitrarily without an overarching psychometric model of stress states. To develop a more systematic multidimensional framework for understanding transient states of mood, arousal, and fatigue, Matthews and his associates (Matthews et al., 1999, 2002) developed the Dundee Stress State Questionnaire (DSSQ) to assess the manner in which stress is experienced as disturbances in affect, motivation, and cognition. The DSSQ features 10 factor-analytically determined scales which measure energetic arousal, tense arousal, hedonic tone, intrinsic task motivation, self-focused attention, self-esteem, concentration, confidence and control, task-relevant cognitive interference, and task-irrelevant cognitive interference. The scales themselves are inter-correlated and support a higher-order factor model that differentiates three broader dimensions known as *Task Engagement, Distress,* and *Worry.* As described by Matthews et al. (2002), Task Engagement incorporates the energetic arousal, motivation, and concentration scales and contrasts enthusiasm and interest in the task with fatigue and apathy. Distress encompasses negative moods and the lack of confidence in one's performance while Worry reflects the level of intrusive thoughts and other negative self-referent cognitions.

A wide array of studies has revealed that vigilance tasks induce a consistent stress portrait on the DSSQ, typically leading to a decrease in Task Engagement and an increase in Distress (Warm, Matthews, et al., 2008). Also it is noteworthy that the DSSQ-determined stress signature for vigilance assignments is distinct from other demanding tasks, such as working memory tasks, which also elicit an increase in Distress but unlike vigilance assignments lead to an increase in Task Engagement.

1.2.2. Temporal Context and Stress

To date, there has been no attempt to assess the effects of the temporal context in which a vigilance task is performed on the DSSQ-determined stress pattern associated with the vigilance assignment. However since temporal cognition can be a significant source of stress (de Pontbriand, Allender, & Doyle 2008) it is conceivable that if, as Sackett et al. (2010) have claimed, "You are having fun when time flies," the temporal context can be moderator variable for task-induced stress in vigilance. Specifically, participants in a *time flies* condition might be expected to provide higher ratings of Task Engagement and lower ratings of Distress, than those in a *time drags* condition. This study was designed to test those expectations. An important point to consider in this regard is that stress induced by an initial exposure to a vigilance task can extend to a subsequent exposure to that task (O'Hanlon, 1965). Consequently, an additional goal for this investigation was to determine if the workload/stress effects induced by manipulations of participants' PTP in an initial exposure to a vigilance task extend to a subsequent exposure to the same task.

1.3. Cerebral Hemovelocity

Neurological evidence of task demand comes from studies using a non-invasive brain imaging system known as Transcranial Doppler sonography (TCD) that employs ultrasound signals to

monitor the mainstem intracranial arteries—the middle (MCA), anterior (ACA), and posterior (PCA) arteries - for changes in cerebral blood flow velocity (CBFV), and thereby to gauge changes in metabolic activity during task performance (Duschek & Schandry, 2003; Tripp & Warm, 2007). These arteries are readily isonated through a cranial “trans-temporal window” and exhibit discernible measurement characteristics that facilitate their identification. Measurement of CBFV via TCD is accomplished with a 2 mHz pulsed Doppler transducer which is placed immediately above the zygomatic arch along the temporal bone, a part of the skull that is functionally transparent to ultrasound, and held in place with a headband. Identification of the different mainstem arteries is accomplished by adjusting the location and depth of the pulse until the desired artery is isonated. The MCA is frequently measured in examinations of vigilance task performance due to the fact that it carries around 80% of the blood flow within each of the cerebral hemispheres (Netter, 1989; Toole, 1984). Functionally, the TCD approach measures the difference in frequency between outgoing and reflected energy as it strikes moving erythrocytes, or red blood cells, within the desired mainstem artery. The resulting magnitude of this frequency shift is directly proportional to the velocity of blood flow.

When a particular area of the brain becomes metabolically active, as is the case in the performance of mental tasks, by-products of that activity, such as carbon dioxide (CO_2), increase. This increase in CO_2 leads to increased blood flow to the region to remove the waste products (Aaslid, 1986; Hellige, 1993). Therefore, TCD offers the possibility of measuring changes in metabolic activity during task performance (Stroobandt & Vingerhoets, 2000). Importantly, the diameters of the ACA, MCA, and PCA remain largely unchanged under varying task demands, indicating that the hemovelocity changes in these larger mainstem arteries are not a function of their own vascular activity (Duschek & Schandry, 2003; Tripp & Warm, 2007). Rather, deviations in CBFV result from changes in the blood demanded by their perfusion territories and thus changes in local neuronal activity. Unlike the positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) techniques used for assessing brain systems underlying human performance, TCD does not provide information about changes in specific brain loci. However, it does provide gross hemispheric data with good temporal resolution (Aaslid, 1986; Duschek & Shandry, 2003) and compared to PET and fMRI, it can track rapid changes in blood flow dynamics that can be followed in real time (Warm, Matthews, & Parasuraman, 2009; Warm & Parasuraman, 2007). Additionally, as noted by Warm and associates (Warm et al., 2009; Warm & Parasuraman, 2007), a benefit of TCD over PET and fMRI is that the low weight and small size of the transducer probe allow for continuous measurement of CBFV that is not restricted by body motion.

1.3.1. Cerebral Blood Flow and the Vigilance Decrement

Recent research has demonstrated that the vigilance decrement is accompanied by a temporal decline in CBFV when participants are actively engaged in a vigilance task, but not when they simply view the task for an equal amount of time without a work imperative. Moreover, the temporal decline in CBFV occurs predominately in the right cerebral hemisphere (Warm & Parasuraman, 2007; Warm et al., 2009). These findings are consistent with the view that a right-hemispheric system is involved in the functional control of vigilance (Langner & Eickhoff, 2012; Shaw et al., 2009; Parasuraman, Warm, & See, 1998; Warm & Parasuraman, 2007) and with a

resource utilization model of vigilance in which it is assumed that a limited-capacity information-processing system allocates resources to cope with situations that confront it and that task performance depletes those reservoirs of energy (Davies & Parasuraman, 1982; Parasuraman & Davies, 1977; Warm & Dember, 1998).

To date, the studies of CBFV which have provided evidence of task demand in vigilance have not examined temporal context effects upon CBFV. There is reason to believe, however, that the temporal context may have an impact on task-related hemovelocity. Previous studies have demonstrated that Task Engagement and CBFV signify a common resource pool for "energization" of information processing (cf., Matthews & Davies, 1998), and that Task Engagement is positively correlated with CBFV while performing brief but demanding computerized tasks (Matthews et al., 2010; Reinerman et al., 2006). Thus, to the extent that deceleration of PTP lowers Task Engagement, it may also reduce CBFV. Consequently, a final concern for this study was to test that possibility.

2.0 METHODS

2.1. Participants

Forty-five individuals (21 males and 24 females) recruited from the Dayton, OH area served as participants for a single payment of $45. They ranged in age from 18-30 years with a mean age of 21.2 years. All participants had self-reported normal or corrected-to-normal vision (via surgery or contact lenses), normal hearing (self-report), and were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The participants were asked to abstain from caffeine, nicotine, and medications for 12 hours prior to serving in the study (Stroobandt & Vingerhoets, 2000). The experiment was conducted under conditions approved by the Wright-Patterson Air Force Base Institutional Review Board.

2.2. Experimental Design

A 3 (Temporal Manipulations) × 2 (Vigils) × 3 (Periods of Watch) split-plot experimental design was employed. Fifteen participants, 7 males and 8 females, were assigned at random to a *time drags* or a *time flies* temporal manipulation condition, and an additional 7 males and 8 females were assigned to a *control* condition in which they were informed of the true length of the vigil with no attempt to manipulate PTP. Participants in the *time drags* condition were instructed that the task would last 15 minutes, while those in the *time flies* condition were told the task would last 60 minutes, and those in the control condition were told the task would last 30 minutes. The actual duration of the vigil was 30 minutes for all participants. Information regarding the expected duration of the vigil was provided on the visual display terminal (VDT), described below, in which the vigilance task was presented. Participants were required to acknowledge this information by pressing the spacebar on a computer keyboard in order to initiate the vigil. Upon initiation, the duration prompt was removed.

2.3. Vigilance Task

The vigilance assignment consisted of two experimental vigils, each divided into 3 continuous 10-minute periods of watch, separated by a 15-minute period during which participants completed surveys. Participants assumed the role of remotely piloted aircraft (RPA) controllers monitoring the flight paths of two RPAs projected on a 17-inch VDT (Hitchcock, Dember, Warm, Moroney, & See, 1999; Hitchcock et al., 2003). As shown in Figure 1, the display consisted of a sector represented by a solid red circle (10.5 mm in diameter; transluminance = 21.4 cd/m^2) surrounded by a thin white border (0.75 mm thick × 12 mm in diameter), three concentric white outer markers (0.75 mm thick, 28, 53, and 83 mm in diameter, respectively; transluminance = 79.9 cd/m^2), and two lines representing RPA flight paths (1 × 25 mm; transluminance = 30.6 cd/m^2).

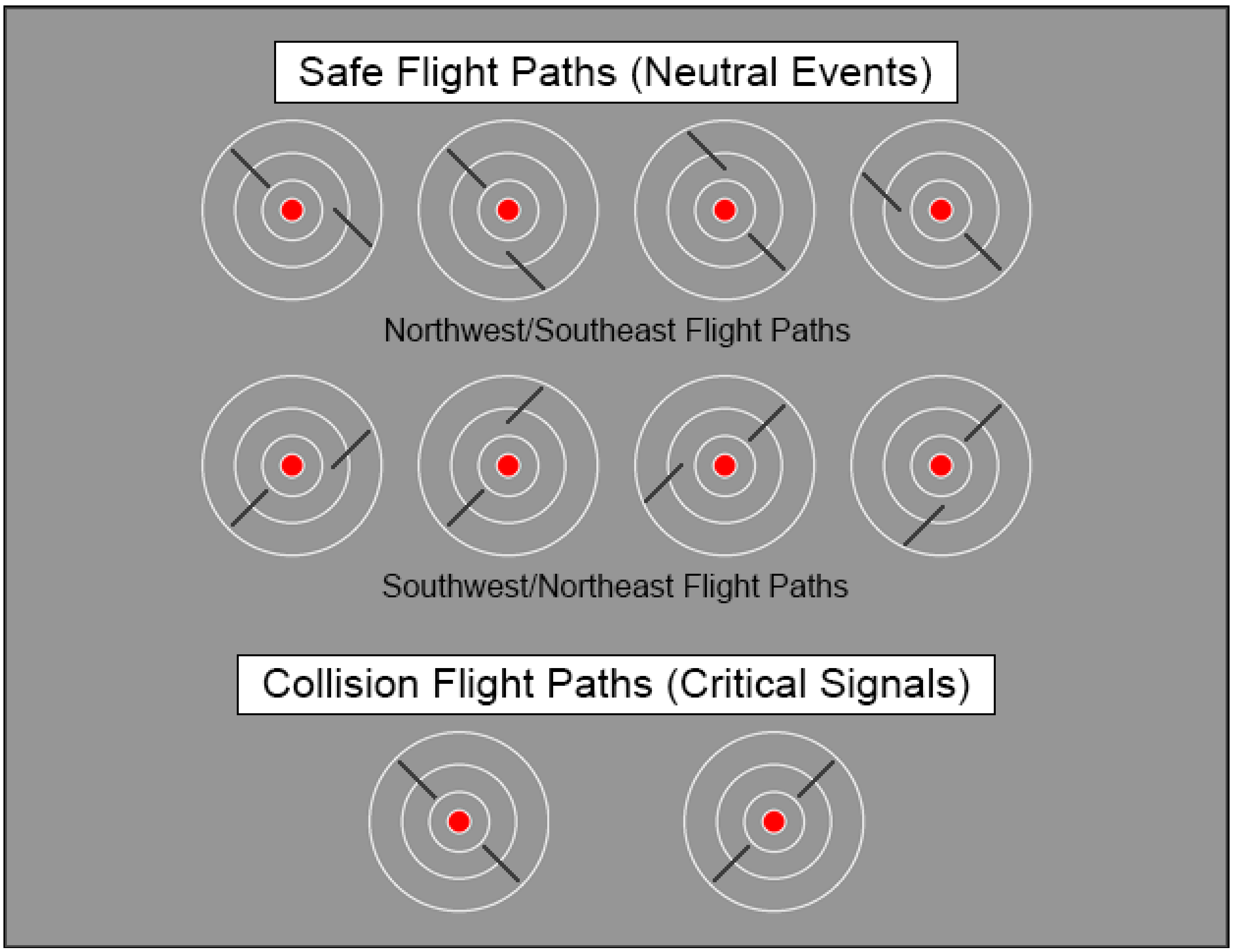

Figure 1. Examples of neutral events (safe flight paths) and critical signals (collision flight paths) in the display. The contrast of the flight paths to the background has been increased in the figure for clarity of presentation.

All stimuli were displayed against a light gray background (transluminance = 29.5 cd/m^2). The Michaelson Contrast ratio ([maximum luminance - minimum luminance / (maximum luminance

+ minimum luminance]; Coren, Ward, & Enns, 1999) of the RPA flight paths to the background was 1.83% (light gray targets on a light gray background). The RPAs approached the inner sector from opposite headings (northwest to southeast or northeast to southwest). One of the two RPAs vectored toward the center of the red sector, while the other RPA was parallel to but slightly displaced to the left or the right, resulting in eight possible safe flight paths or neutral events. Critical signals for detection were cases in which both of the RPAs vectored toward the center of the sector on a potential collision path in either the northwest to southeast or the northeast to southwest heading. In all experimental conditions, the display was updated 30 times/minute with a dwell time of 80 ms (see Kamzanova, Kustubayeva, & Matthews, 2012). For each participant, 5 critical signals occurred at random intervals in each flight path heading during each period of watch (overall signal probability = 3.33%). Participants indicated their detection of critical signals by pressing the spacebar on a computer keyboard. Responses made within 1200 ms of critical signal onset were considered as correct detections or "hits." All other responses were considered as errors of commission or "false alarms."

All participants were tested in a 2.48 × 2.45 × 2.16 m windowless sound-attenuated booth. The VDT was mounted on a table 70 cm directly in front of the seated participant (visual $\text{angle}_{\text{VDT}}$ = 32.87°; visual $\text{angle}_{\text{stimulus display}}$ = 6.79°). Ambient illumination in the testing booth was 2.5 cd/m^2, provided by a fixture containing two 17-watt fluorescent lamps, occluded on all sides and positioned above and adjacent to the seated participant in order to minimize glare on the VDT.

Upon reporting for the experiment, participants surrendered all timepieces and electronic devices. All clocks were removed from the laboratory room and the date and time were removed from the VDT.

Prior to serving in the first experimental vigil, participants completed a pre-task version of the DSSQ, a baseline measure of CBFV (described below), and a 5-minute practice session to familiarize them with the task. During the practice session, a computerized female voice (50 dBA) provided feedback pertaining to correct detections, misses, and false alarms. Participants were required to correctly detect at least 5 of 10 critical signals and commit no more than 12 false alarms during the practice session in order to be considered for inclusion in the final analysis. All participants in the three temporal manipulation conditions met these qualifying criteria. During the experimental vigil, audio feedback was removed.

Upon the conclusion of vigil 1, participants indicated how time seemed to progress with a computer-controlled 7-point scale (1 = time dragged, 4 = pretty normal, 7 = time flew). They then used 7-point scales to assess their evaluation of the task in terms of enjoyment, challenge, engagement, fun, skill required, pleasantness, excitement to participate in a similar task in the future, and excitement to participate in a longer task in the future. The nature of the scales and their order of presentation were drawn from the procedure employed by Sackett et al. (2010). Following completion of the temporal and hedonic evaluation scales used by Sackett et al., participants completed the NASA-TLX followed by a post-task version of the DSSQ. Stimulus presentations, vigilance response recording, the temporal and hedonic evaluation scales, and the NASA-TLX and DSSQ presentations/responses were controlled by a Dell PC running Windows XP.

Following the 15-minute interval for survey completion, participants began vigil 2 which was procedurally identical to vigil 1 in all respects except that no information was given regarding the temporal duration of the vigil. At the conclusion of vigil 2, participants again indicated how time seemed to progress before completing the temporal and hedonic evaluation scales, and the NASA-TLX followed by the post-task DSSQ. After participants completed these scales in vigil 2, the experimenter probed for suspicion regarding the time manipulation with a funnel debriefing procedure designed by Harmon-Jones, Amodio, and Zinner (2007).

For the entirety of the experiment, bilateral hemovelocity measurements were taken from participants in all conditions from the left and right medial cerebral arteries using a Nicolet Companion III Transcranial Doppler unit equipped with two 2 mHz ultrasound transducers embedded in a plastic bracket and secured to the participant's head by a headband. Measurement started five minutes prior to the beginning of the practice session and concluded when the participant finished all of the surveys following vigil 2. Given that raw cerebral hemovelocity scores can vary extensively across individuals based on characteristics such as sex and age (Adams, Nichols, & Hess, 1992), CBFV values for vigils 1 and 2 were expressed as a proportion of the last 60 seconds of their 5-minute resting baselines prior to vigils 1 and 2, respectively, to control for this variability. This baseline index was recommended by Aaslid (1986) and has been utilized in numerous studies of cerebral hemovelocity and vigilance (see Hitchcock et al., 2003; Hollander et al., 2004; Funke et al., 2011; Shaw et al., 2009; Funke et al., 2012).

3.0 RESULTS

3.1. Performance

As is frequently the case in vigilance experiments, performance efficiency was assessed in terms of signal detection theory measures of perceptual sensitivity (*d'*) and response bias (*c*; Wickens et al., 2013). The measure *c* was employed instead of the more traditional measure β because of data indicating that *c* is a more effective measure of response bias in vigilance studies (See, Warm, Dember, & Howe, 1997).

Mean *d'* scores for the temporal manipulation conditions are plotted as a function of vigil and period of watch in Figure 2. The data were tested for statistical significance by means of a 3 (Temporal Manipulation) × 2 (Vigil) × 3 (Period of Watch) mixed-model analysis of variance (ANOVA). In this and subsequent ANOVAs, Box's epsilon was employed when appropriate to correct for violations of the sphericity assumption (Maxwell & Delaney, 2004). Significant main effects were obtained for vigil, F (1, 42) = 9.86, $p < .005$, $\eta_p^2 = .19$, and period of watch, F (1.99, 83.49) = 15.05, $p < .001$, $\eta_p^2 = .26$. All other sources of variance in the analysis lacked significance, $p > .05$ in all cases. Perceptual sensitivity was greater in vigil 1 (M = 2.50, SE = 0.12) than in vigil 2 (M = 2.25, SE = 0.13) and as can be seen in the figure, perceptual sensitivity declined over time in both vigils in a comparable manner. The overall mean *d'* scores in vigils 1 and 2 fall within the range of task difficulty from moderately easy to moderately difficult (Craig, 1984).

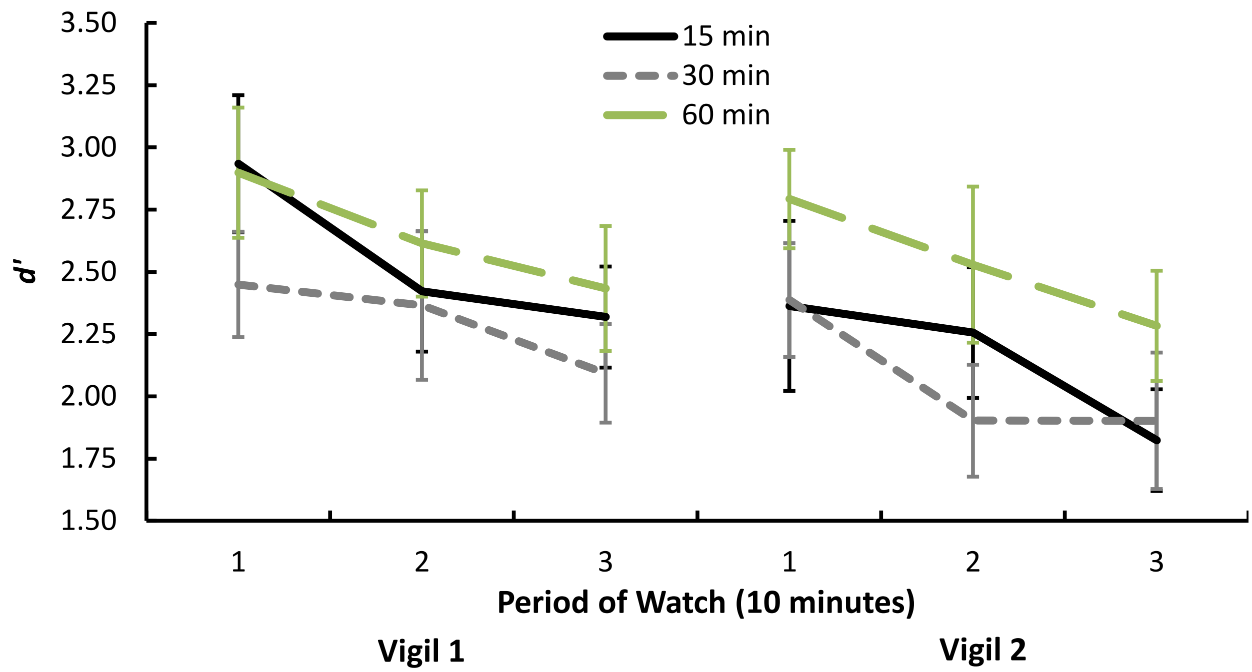

Figure 2. Mean *d'* scores in the three temporal manipulation conditions as a function of period of watch within each vigil. Error bars are standard errors.

Mean *c* scores for the three temporal manipulation conditions are plotted as a function of vigil and period of watch in Figure 3. As in the case of the *d'* scores, a 3 × 2 × 3 mixed-model ANOVA of the *c* scores revealed significant main effects for vigil, $F\ (1, 42) = 8.60$, $p < .01$, $\eta_p^2 = .17$, and period of watch, $F\ (1.95, 81.91) = 30.02$, $p < .001$, $\eta_p^2 = .42$. All of the other sources of variance in the analysis lacked significance, $p > .05$. Participants were more conservative in vigil 2 ($M = 1.0$, $SE = .061$) than in vigil 1 ($M = .86$, $SE = .058$) and as is evident in the figure, they became more conservative over time in a comparable manner in both vigils.

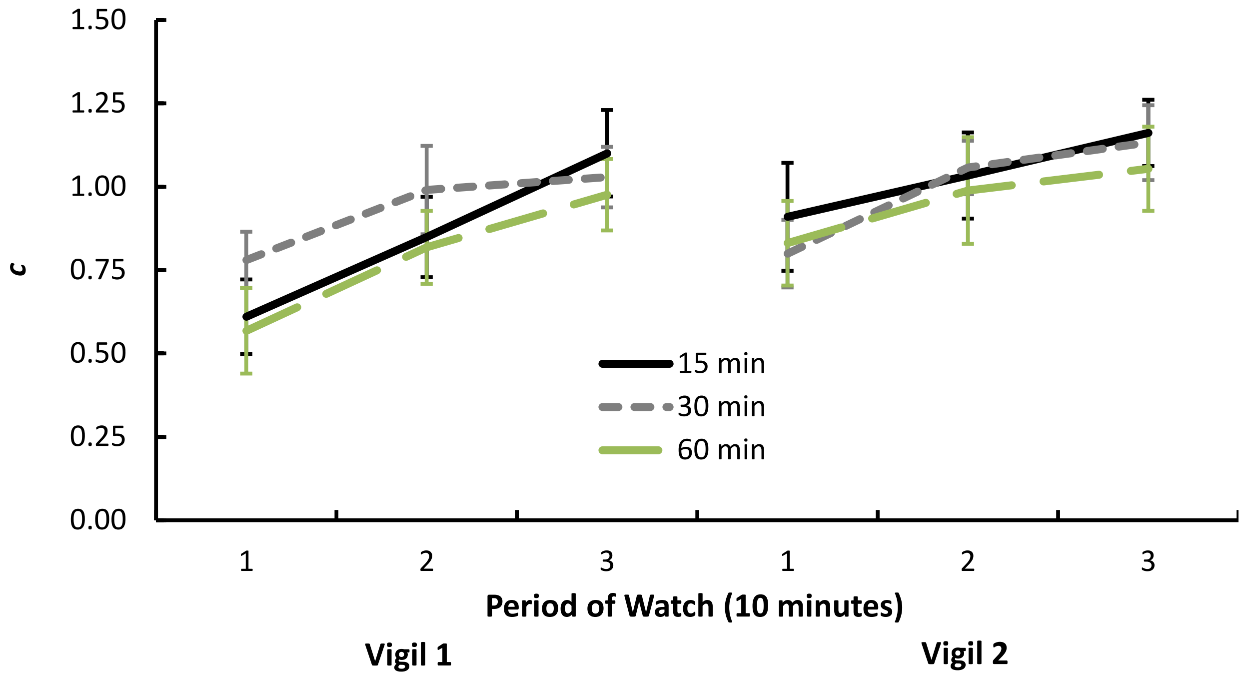

Figure 3. Mean *c* scores in the three temporal manipulation conditions as a function of period of watch within each vigil. Error bars are standard errors.

3.2. Subjective Measures

3.2.1. Perception of Time Progression

Mean PTP scores for the three temporal manipulation conditions in vigils 1 and 2 are presented in Figure 4. It is evident in the figure that in both vigils the PTP scores for the 60-minute condition were between two and three times larger than those in the 15- and 30-minute conditions, indicating that time progression was much faster (higher score) in the former condition than the latter two. A 3 (Temporal Manipulation) × 2 (Vigil) mixed-model ANOVA revealed a significant difference between the temporal manipulation conditions, F (2, 42) = 18.87, $p < .001$, $\eta_p^2 = .47$. The main effect for vigil and the Temporal Manipulation × Vigil interaction lacked significance, $p > .05$ in both cases. Bonferroni-corrected *t*-tests with alpha set at .05 indicated that PTP in the 60-minute condition (*M* = 4.13, *SE* = .51) was significantly faster than in both the 15-minute (*M* =1.53; *SE* = .21) and 30-minute (*M* = 1.73; *SE* = .17) conditions; effect sizes for both tests were *d* = 1.78 and *d* = 1.69, respectively. The difference between the 15-minute and 30-minute conditions was not significant.

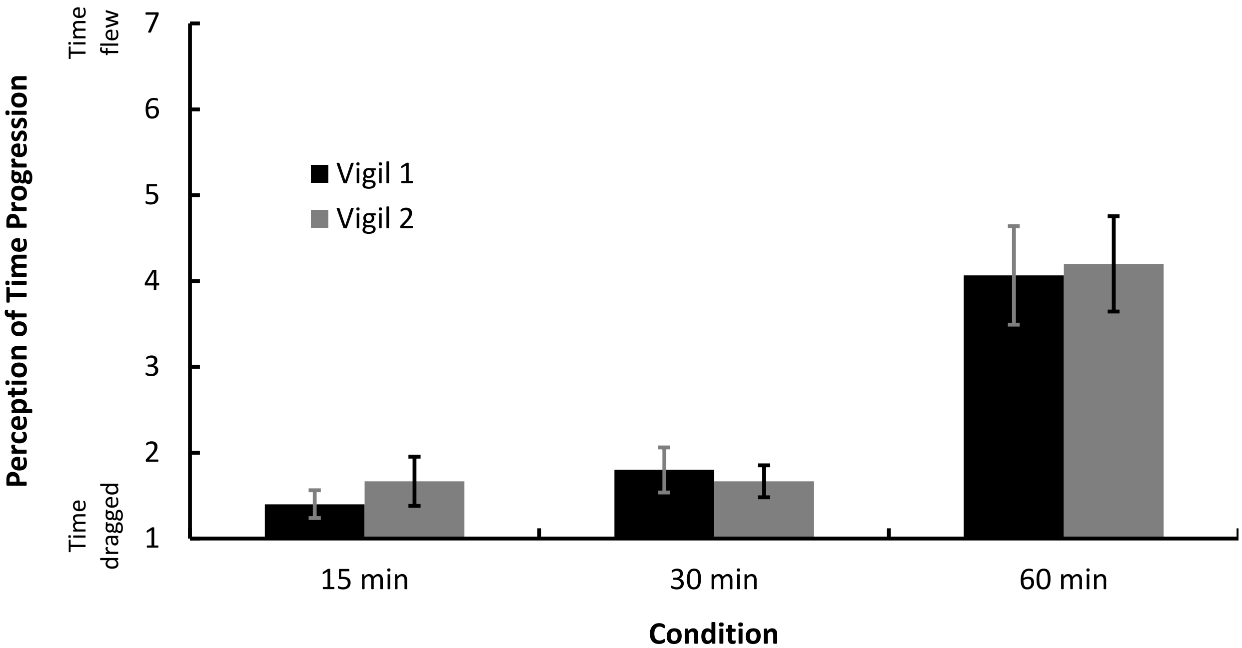

Figure 4. Mean PTP ratings in the three temporal manipulation conditions for each vigil. Error bars are standard errors.

In the present study, the hedonic ratings of task enjoyment, challenge, engagement, fun, skill required, pleasantness, excitement to reengage in a similar task, and excitement to reengage in a longer task were closely related for the three temporal manipulation conditions within each vigil (Chronbach's $\alpha = .73$ for each vigil). Accordingly, following the procedure adopted in the Sackett et al. (2010) studies in which there was a similar close association among the hedonic ratings in each experimental condition, the ratings were combined into a composite measure of enjoyment on a 1-7 scale for each temporal manipulation condition within each vigil. These data are plotted in Figure 5. It is evident in the figure that the means for all conditions were around 3 or less indicating that the participants' ratings of enjoyment were generally low. A 3 (Temporal Manipulation) × 2 (Vigil) mixed-model ANOVA, revealed that the mean enjoyment composite for vigil 1 (M = 3.07, SE = .12) was significantly greater than that for vigil 2 ($M = 2.65$, $SE = .12$), $F\ (1, 42) = 25.84$, $p < .001$, $\eta_p^2 = .38$. All of the remaining sources of variance in the analysis lacked significance, $p > .05$ in each case. Evidently, along with its low value, the composite enjoyment rating declined from vigil 1 to vigil 2 and the temporal context did not affect the hedonic evaluation of the vigilance task.

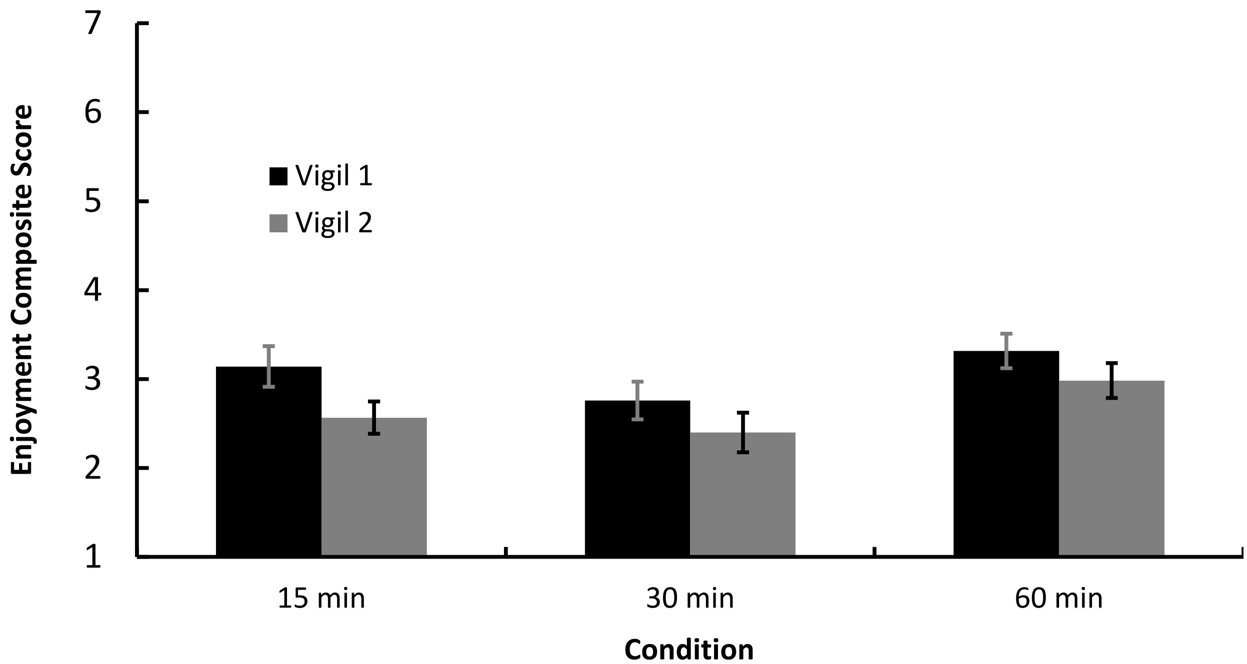

Figure 5. Mean Enjoyment scores in the three temporal manipulation conditions within each vigil. Error bars are standard errors.

Of the 45 participants, 6 participants in the 15-minute condition, 0 in the 30-minute condition, and 8 participants in the 60-minute condition indicated that they suspected a timing inaccuracy during the funnel debriefing. Removing these participants from the performance, PTP, hedonic, workload, and CBFV analyses did not change any of the conclusions reached in these analyses.

3.2.2. NASA-TLX Workload

The unweighted scoring procedure (Nygren, 1991) was used in calculating NASA-TLX values. Mean NASA-TLX global scores for the three temporal manipulation conditions in each of the two vigils are displayed in Table 1. The table testifies that that the participants found the workload of the vigilance task to be high in all experimental conditions since the scores in each of these conditions were above the midpoint of the NASA-TLX scale (50). A 3 (Temporal Manipulation) × 2 (Vigil) mixed-model ANOVA indicated that the global workload scores were significantly higher in vigil 1 than in vigil 2, F (1, 42) = 4.05, p = .05, η_p^2 = .09. However, the main effect for temporal manipulation lacked significance as did the Temporal Manipulation × Vigil interaction, p > .05 in both cases.

Table 1

Mean NASA-TLX Global Workload Scores for the Three Temporal Manipulation Conditions within Vigil 1 and Vigil 2. Standard Errors are in Parentheses

	Vigil		
Condition	1	2	*M*
15 minute	59.88 (5.16)	55.44 (5.18)	57.66
30 minute	61.47 (2.85)	58.56 (3.03)	60.01
60 minute	53.86 (4.56)	51.83 (3.49)	52.84
M	58.40	55.28	

Although variation in the temporal framework in which the vigilance task was performed had no effect on global workload, it is possible that the effect of such manipulation might appear on one or more of the NASA-TLX subscales. Mean NASA-TLX subscale scores for the three temporal manipulation conditions are presented for each vigil in Figure 6. The only significant source of variance in a 3 (Temporal Manipulation) × 2 (Vigil) × 6 (Subscales) mixed-model ANOVA of these data was for subscales, F (4.06, 170.67) = 47.46, $p < .001$, $\eta_p^2 = .53$. Clearly, the temporal framework in which the vigilance task was performed in vigil 1 and vigil 2 did not influence the perceived workload of the task in terms of either the global workload or individual subscale scores. In regard to the subscale differences, post-hoc Tukey tests with alpha set at .05 revealed that the means for Mental Demand (*M* = 73.01, *SE* = 3.26), Temporal Demand (*M* = 69.40, *SE* = 3.51), and Effort (*M* = 68.81, *SE* = 3.52) were significantly greater than the means for Physical Demand (*M* = 20.27, *SE* = 3.48), Performance (*M* = 52.61, *SE* = 3.17), and Frustration (*M* = 56.93, *SE* = 3.75). Also, Performance and Frustration were significantly greater than Physical Demand.

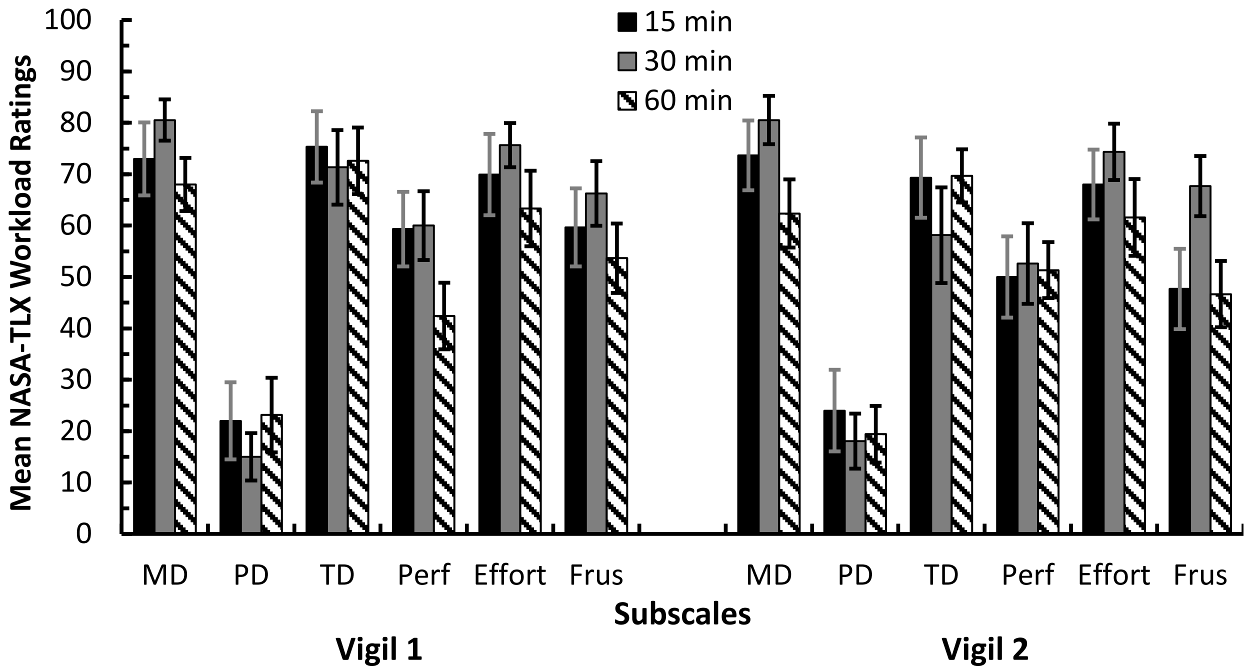

Figure 6. Mean NASA-TLX workload ratings provided for each subscale in the three temporal manipulation conditions within each experimental vigil. Error bars are standard errors.

3.2.3. Dundee Stress-State Questionnaire Factors

Pre-task, post-vigil 1, and post-vigil 2 scores for the Worry, Task Engagement, and Distress scales of the DSSQ were standardized against a large normative group (Matthews et al., 2002) based on the formula: (*raw score –mean of the normative sample*) / (*standard deviation of the normative sample*). Factor scores for Worry, Task Engagement, and Distress were calculated using regression weights from the normative sample. Factor scores are distributed with a mean of 0 and a standard deviation of 1, so that values calculated for a sample represent a deviation from normative values in standard deviation units.

Mean pre-task scores for the three temporal manipulation conditions are presented in Figure 7. Two manipulation checks were performed. The first was to determine if the conditions differed from each other on any of the DSSQ scales prior to receiving the experimental manipulation. Toward that end, *t*-tests were used to probe for condition differences on the mean pre-task scores for each DSSQ scale. No significant differences were found between the three conditions for any of the scales, $p > .05$ in each case. Thus, any experimentally-based condition difference in the temporal manipulation conditions on any of the three DSSQ scales cannot be attributed to initial sampling artifacts.

The second manipulation check was to determine how the three temporal manipulation conditions compared to the DSSQ normative sample on the Worry, Task Engagement, and Distress scales at the outset of the experiment using the standardization *z-scores*. Since the pre-task scores for the three conditions did not differ significantly from each other on any of the

DSSQ scales, the means of the three conditions on each scale were tested against a z-value of 0 by using Bonferroni-corrected *t*-tests with alpha set at .05. The mean for the Worry scale did not differ significantly from the normative mean of 0. However, the mean for the Task Engagement scale (0.69, *SE* =.09) was significantly greater than the normative mean, t (44) = 7.74, $p < .001$, d = .84, and the mean for the Distress scale (-0.47, *SE* = .10) was significantly below the normative value of 0, t (44) = 4.60, $p < .001$, d = .55. Evidently, at the outset of this study, the participants were more engaged and less distressed than the normative sample.

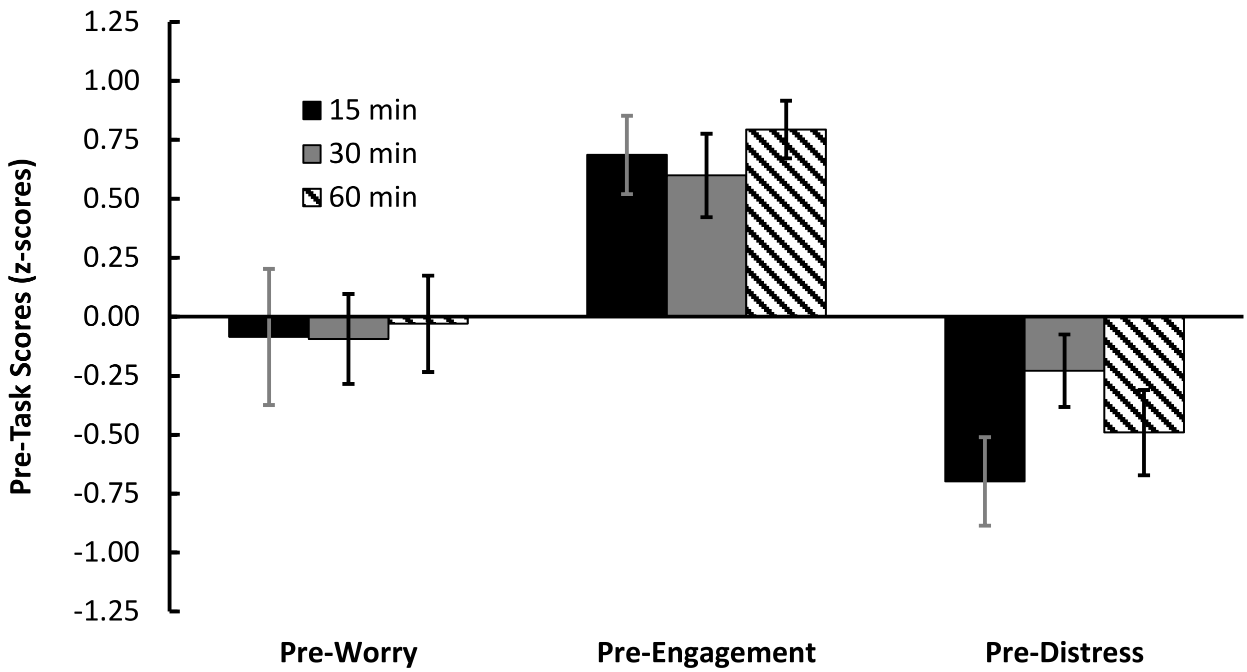

Figure 7. Pre-task scores on the Worry, Task Engagement, and Distress scales of the DSSQ for the three temporal manipulation conditions. Error bars are standard errors.

To assess condition-related changes in each factor across the experiment, means of the three temporal manipulation conditions were examined in conjunction with the three scale administrations (pre-task, post-vigil 1, post-vigil 2) by means of 3 (Temporal Manipulation) × 3 (Administration) mixed-model ANOVAs for each DSSQ scale.

No significant sources of variance were noted for the Worry factor, $p > .05$ in each case, indicating that there were no differences between the three temporal manipulation conditions and that Worry did not change across administrations.

Mean Task Engagement scores for each of the three temporal manipulation conditions are plotted as a function of administration (pre-task, post-vigil 1, post-vigil 2) in Figure 8. It is evident in the figure that Task Engagement decreased over the three administrations and that the magnitude of the decrease was not uniform across the temporal manipulation conditions. These impressions were confirmed by the ANOVA of the data of Figure 8, which revealed significant main effects for temporal manipulation, F (2, 42) = 5.03, $p < .05$, $\eta_p^2 = .19$, administration, F

(1.44, 60.56) = 102.52, $p < .001$, $\eta_p^2 = .71$, and a significant Temporal Manipulation × Administration interaction, F (2.88, 60.56) = 3.57, $p < .05$, $\eta_p^2 = .15$. Follow-up Bonferonni-corrected t-tests with alpha set at .05 revealed that in both the 15- and 30-minute conditions, the scores for Task Engagement declined significantly from pre-task to post-vigil 1 and from post-vigil 1 to post-vigil 2. By contrast, while the scores in the 60-minute condition declined significantly from pre-task to post-vigil 1, they did not differ significantly from post-vigil 1 to post-vigil 2.

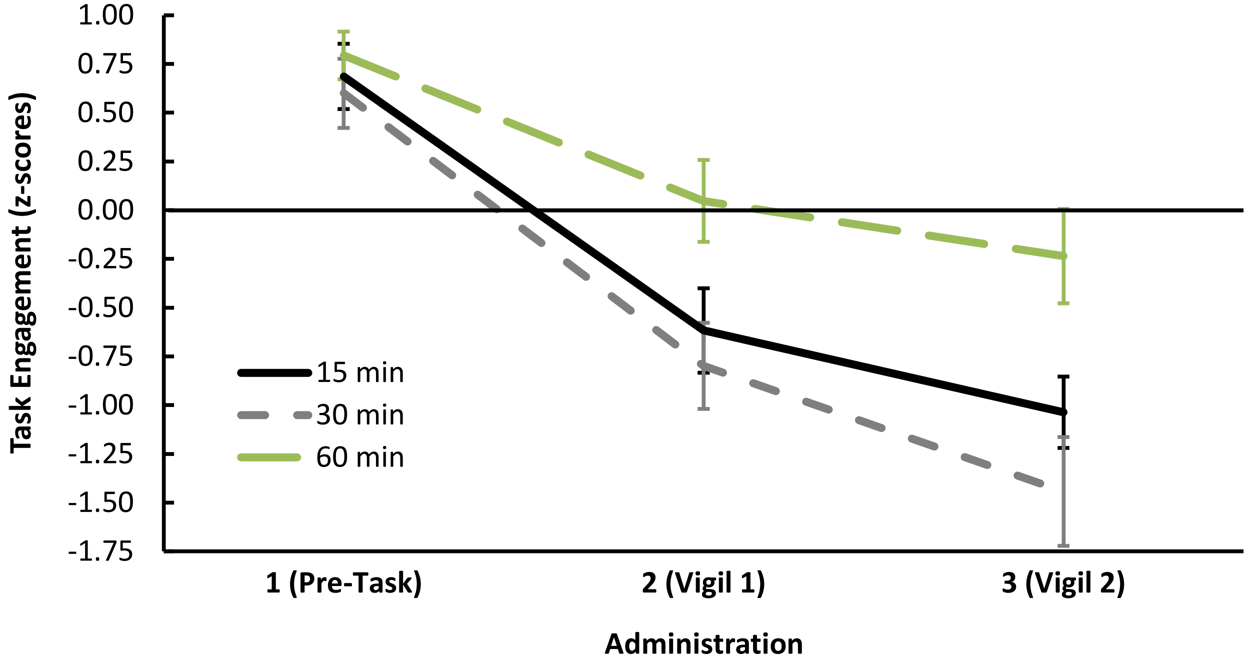

Figure 8. Mean Task Engagement scores on the DSSQ for the three temporal manipulation conditions as a function of administration. Error bars are standard errors.

Mean Distress scores for the three temporal manipulation conditions are plotted as a function of administration in Figure 9. The only significant source of variance in the ANOVA of the Distress data was a main effect for administration, F (1.49, 62.74) = 50.83, $p < .001$, $\eta_p^2 = .55$. Figure 9 shows that across the temporal manipulation conditions, the Distress scores increased sharply from pre-task to post-vigil 1 and remained at approximately the same level following vigil 2.

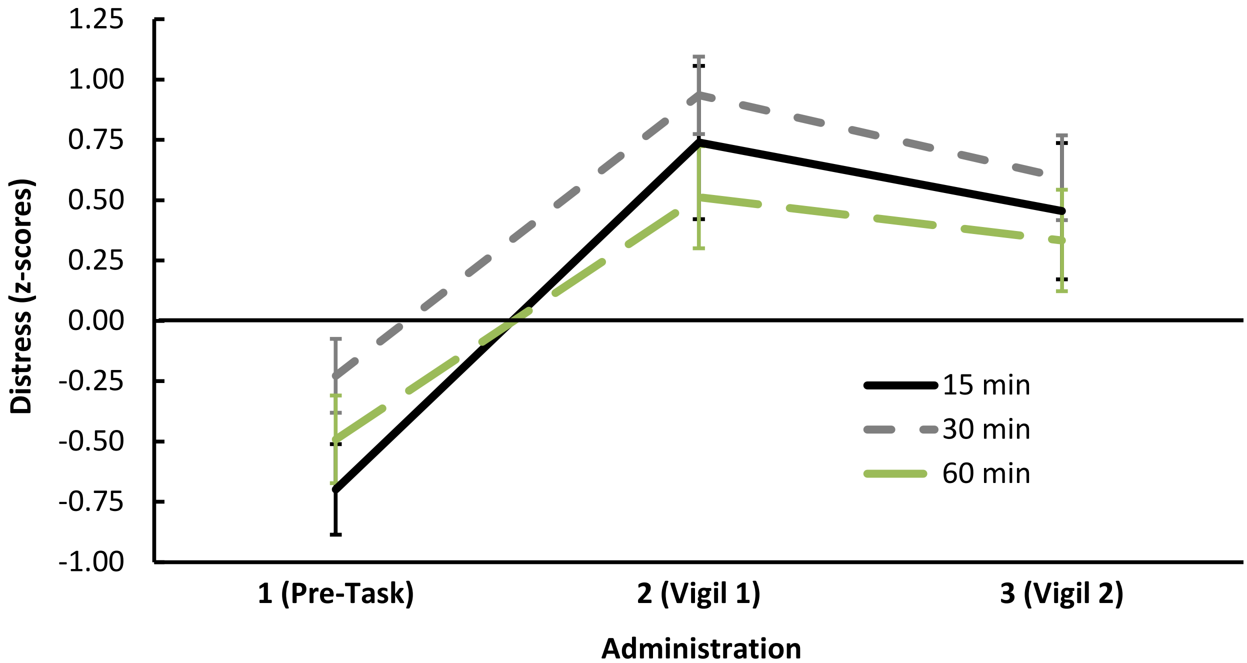

Figure 9. Mean Distress scores on the DSSQ for the three temporal manipulation conditions as a function of administration. Error bars are standard errors.

3.3. Cerebral Bloodflow Velocity

Raw CBFV resting baseline values were examined for condition differences prior to starting the practice session and prior to starting vigil 2. A 3 (Temporal Manipulation) × 2 (Hemisphere) × 2 (Vigil) mixed-model ANOVA of the raw CBFV values revealed no significant differences between conditions, hemispheres, and vigils, and no interactions between any of these factors, $p > .05$ in all cases. Thus, any CBFV effects noted within the two cerebral hemispheres and the two vigils associated with the temporal manipulation cannot be attributed to sampling artifacts in the resting baselines.

Also, the lack of a significant difference in the two pre-vigil baselines indicates that CBFV returned to pre-vigil 1 levels before participants began vigil 2. Apparently the 15-minute period following the completion of vigil 1, during which participants filled out surveys, allowed enough time for this return in CBFV to occur. A finer moment-to-moment analysis of the speed at which CBFV returned to baseline levels during the 15-minute interim is provided below.

Mean CBFV values of participants in each of the three temporal manipulation conditions within each vigil are plotted as a function of period of watch in Figure 10. Data for the left and right hemispheres are presented in separate panels. A 2 (Hemisphere) × 3 (Temporal Manipulation) × 2 (Vigil) × 3 (Period of Watch) mixed-model ANOVA revealed significant main effects for hemisphere, F (1, 42) = 35.88, $p < .001$, $\eta_p^2 = .46$, vigil, F (1, 42) = 4.74, $p < .05$, $\eta_p^2 = .10$, and period, F (1.58, 66.51) = 17.14, $p < .001$, $\eta_p^2 = .29$, and significant interactions between vigil and period, F (1.91, 80.40) = 13.13, $p < .001$, $\eta_p^2 = .24$, and vigil and hemisphere, F (1, 42) = 5.44, p

< .05, $\eta_p^2 = .12$. All of the remaining sources of variance in the analysis were not significant, $p >$ .05 in each case.

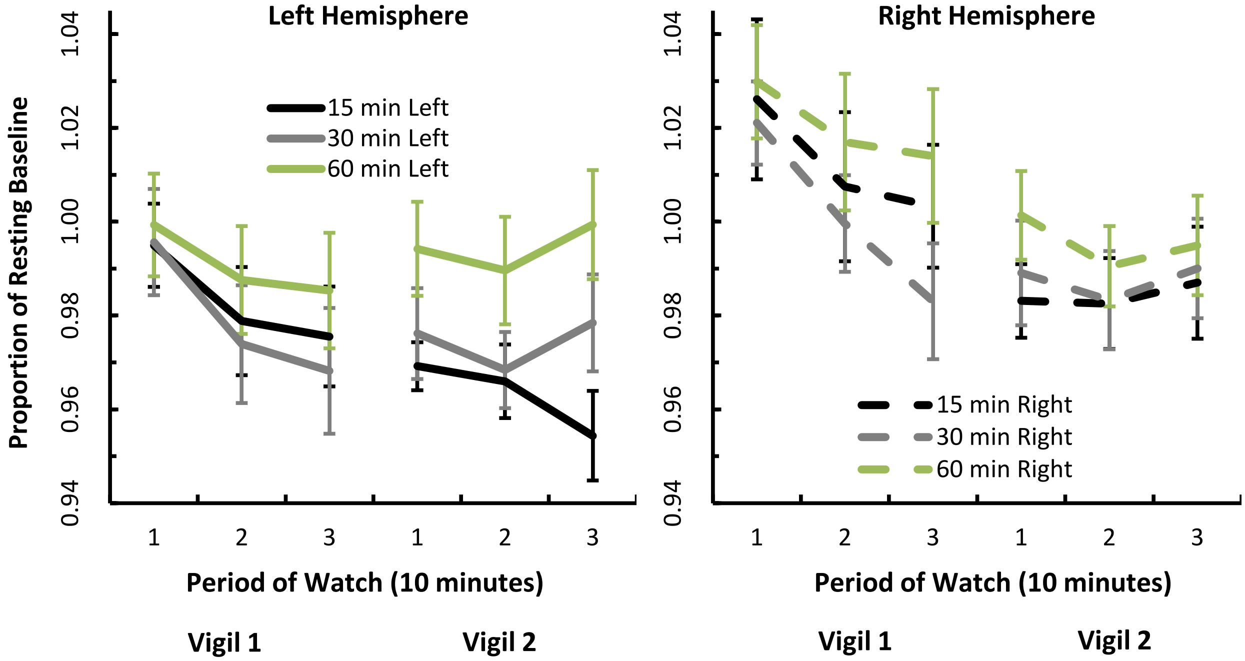

Figure 10. Hemovelocity scores in the left and right cerebral hemispheres for the three temporal manipulation conditions as a function of period of watch within each vigil. Error bars are standard errors.

The Vigil × Period interaction is presented in Figure 11. Separate ANOVAs for period within each vigil found that CBFV declined significantly over period of watch in vigil 1, F (1.81, 76.12) = 30.96, $p < .001$, $\eta_p^2 = .42$, but remained stable over periods in vigil 2, F (1.65, 69.19) = 1.55.

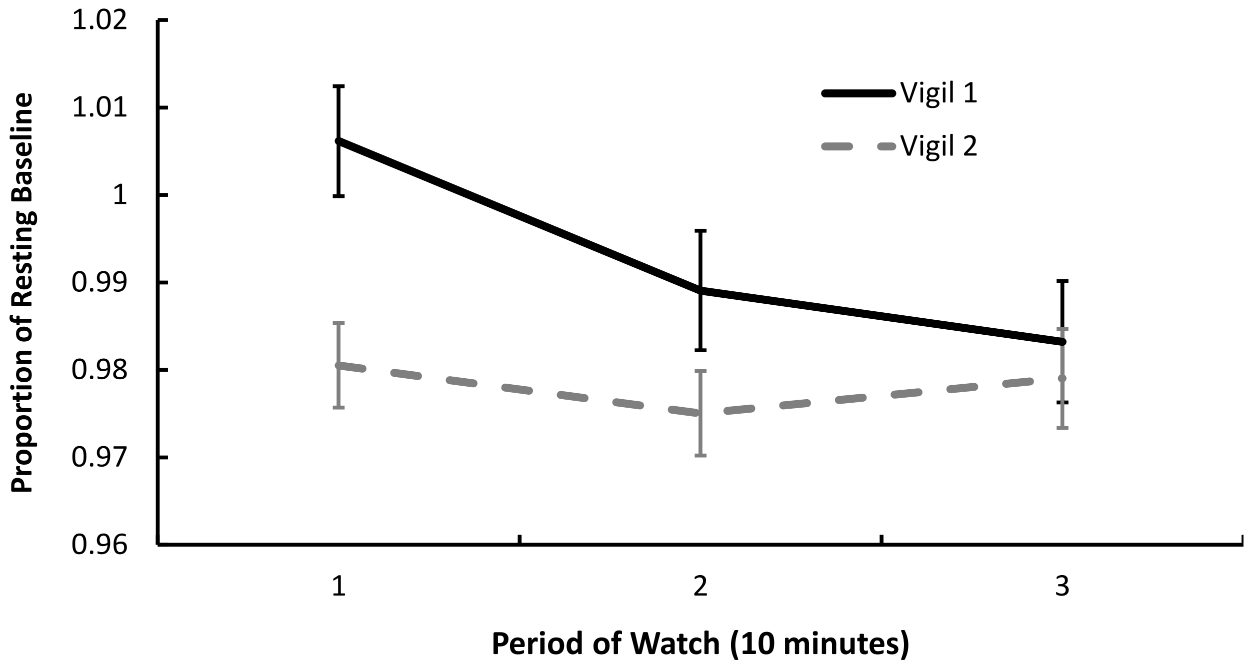

Figure 11. Mean hemovelocity scores across the three periods of watch are displayed for vigil 1 and vigil 2. Error bars are standard errors.

The Vigil × Hemisphere interaction is displayed in Table 2. Bonferroni-corrected *t*-tests with alpha set at .05 indicated that in the right hemisphere the CBFV scores for vigil 1 were significantly higher than those for vigil 2. No differences in hemovelocity between the two vigils were noted in the left hemisphere.

Table 2

Mean Hemovelocity Scores for the Left and Right Cerebral Hemisphere within Vigil 1 and Vigil 2. Standard Errors are in Parentheses

	Vigil		
Hemisphere	1	2	*M*
Left	0.98 (.006)	0.97 (.005)	0.98
Right	1.01 (.007)	0.98 (.006)	1.00
M	1.00	0.98	

Given that CBFV values averaged across the final period of vigil 1 were significantly below the pre-vigil baseline of 1.0, $t\ (44) = 2.42$, $p < .05$, one might ask what happens to CBFV following an experimental vigil and how long it takes CBFV to return to pre-vigil baseline levels. To that end, CBFV values were averaged over 30-second epochs and are plotted over the 15-minute interim between the end of vigil 1 and the beginning of vigil 2 in Figure 12. The cerebral

hemispheres are plotted in adjacent panels due to significant differences found in the main analysis, and CBFV values are collapsed across the temporal manipulation conditions due to the lack of a significant difference for these conditions. In this figure, error bars are 95% confidence intervals, which were employed to test each of the values in the figure against a hypothesis of 1.0 (pre-vigil 1 baseline). Significant deviations from the baseline were indicated by any value in which the confidence intervals did not cross 1.0 (Fisher & van Belle, 1993; Tryon, 2001).

It is clear in Figure 12 that CBFV in both hemispheres quickly returned to pre-vigil 1 levels within the first 30-second epoch, even surpassing it in the left hemisphere. From 31-90 seconds, CBFV briefly drops below the baseline for both hemispheres before returning to baseline levels again around the 120-second epoch. From that point, fluctuations are seen within each cerebral hemisphere over the remaining 13 minutes of the 15-minute period but in general, CBFV remained at baseline level for the remainder of the return period.

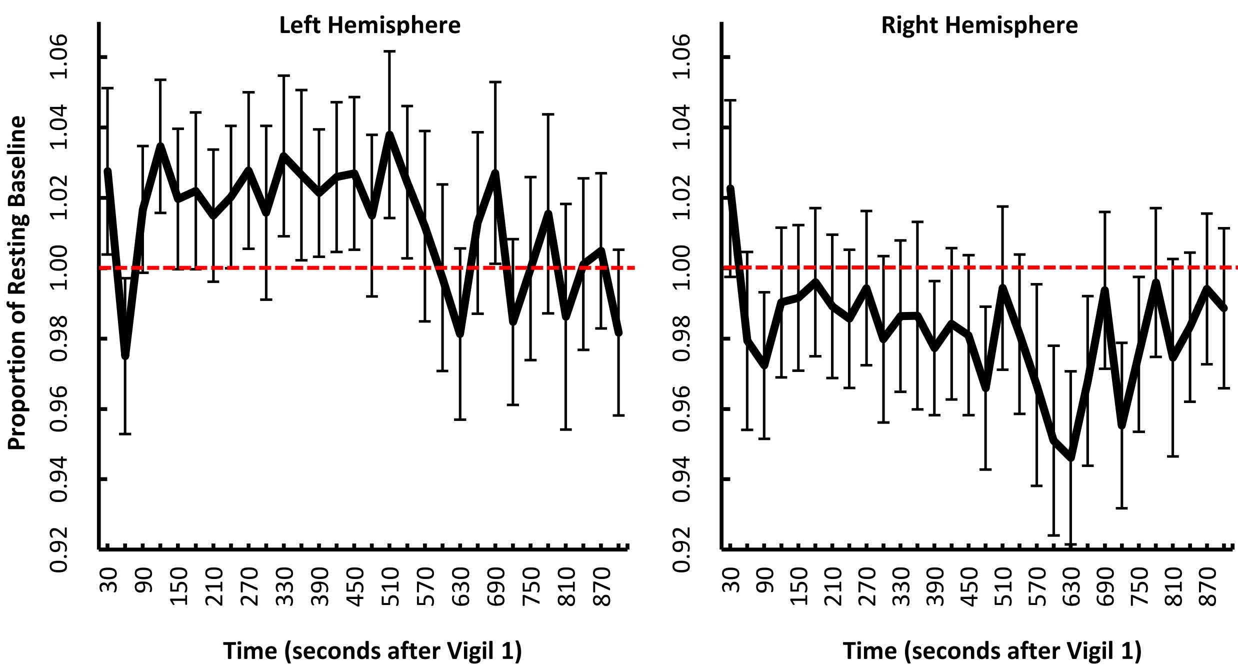

Figure 12. Hemovelocity scores in the left and right cerebral hemispheres for the three temporal manipulation conditions plotted in 30-second epochs following the conclusion of vigil 1. Error bars are 95% confidence intervals.

4.0 DISCUSSION

The present study was designed to examine the possibility that the temporal context in which a vigilance task is performed can be a moderator variable for the subjective evaluation of task-induced workload and stress and for changes in cerebral hemodynamics associated with task performance. Toward that end, we utilized the procedure designed by Sackett et al. (2010) to manipulate participants' PTP by creating a mismatch between the time they expected to perform the task and the time they actually worked on it.

Consistent with Sackett et al.'s (2010) findings, PTP was significantly slower for participants in which actual task duration (30 minutes) exceeded the expected task duration (15 minutes), a *time drags* condition, than for those in which actual task duration (30 minutes) was less than the expected duration (60 minutes), a *time flies* condition. In addition to showing that the effects on PTP produced by the time manipulation procedure employed by Sackett and his colleagues can be seen in an initially performed vigilance task, the present study demonstrated the strength of these effects on PTP by showing that they persisted when participants performed a subsequent vigilance task in which they received no information regarding expected task duration.

A key element in the Sackett et al. (2010) study was the finding that accelerating participants' PTP led to higher ratings of task enjoyment in comparison to a condition in which PTP was decelerated. This led Sackett and his colleagues to suggest that subjective time progression can influence the hedonic evaluation of experience as reflected in their statement "You are having fun when time flies." Contrary to the findings of Sackett et al., the present study did not find that increasing participants' PTP enhanced task enjoyment. Rather, participants in both the *time drags* and *time flies* conditions provided generally low ratings of task enjoyment. A result of that sort is consistent with a substantial array of findings indicating that vigilance tasks are experienced by participants as unpleasant and stressful. Evidently one does not always have fun when time flies. Additional support for the view that vigilance tasks promote negative emotional reactions is the finding that control participants who were not misled about expected task duration also found the vigilance task to be unenjoyable.

In regard to the central questions about whether the temporal context in which a vigilance task is performed can serve as a moderator variable for perceived workload and stress and for task-related changes in cerebral hemodynamics, the answers are "no" and "yes." Although the PTP scores differed significantly across the temporal manipulation conditions, workload ratings were no different in these conditions. As is typical in vigilance tasks (Warm et al., 1996; Warm, Matthews, et al., 2008; Warm, Parasuraman, et al., 2008), global scores on the NASA-TLX fell at the upper level of the scale in all three temporal manipulation conditions indicating that the perceived mental workload in those conditions was high, and the manipulation conditions had no effect upon the workload profile in which mental demand and temporal demand were the principal contributors to workload. Evidently, vigilance is hard work when time *flies* or *drags*. Similarly, the temporal manipulation conditions had no effect on cerebral hemovelocity.

In terms of stress, participants reported feeling more distressed and less engaged after completing their vigilance assignments than they did during the initial baseline measurement phase of the study, a result that is consistent with prior findings with the DSSQ stress scale (Warm, Matthews, et al., 2008). The temporal manipulation conditions had no differential effect on feelings of distress but they did on the degree of Task Engagement. In the conditions in which PTP seemed to *drag*, the 15-minute and the control condition, Task Engagement dropped consistently across administrations from pre-task to post-vigil 1 and then to post-vigil 2. By contrast, in the case in which PTP seemed to *fly*, the 60- minute condition, the drop in Task Engagement across administrations was much less steep. While the scores in this condition declined significantly from pre-task to post-vigil 1, they did not differ significantly from post-

vigil 1 to post-vigil 2. Evidently, the relation between the temporal envelope in which a vigilance task is performed and task-induced stress is complex. The ability of the envelope to mitigate the stress of a vigilance assignment depends on the stress dimension involved. Making time seem to *fly* seems to reduce the degree to which participants lose enthusiasm and interest compared to when time appears to *drag*, while their feelings of distress appear to be unaffected by variations in PTP.

In addition to the task-related dimensions considered above, there is the possibility that temporal orientation might affect vigilance performance itself. McGrath and O'Hanlon (1967) explored that possibility by testing participants under conditions in which a clock in the testing room ran at a normal rate or at a fast or slow rate. Clock rate had no effect on signal detection. The present study offered another opportunity to examine the role of temporal orientation on vigilance performance because at task outset, participants were confronted with large differences in the expected duration of the task they were to perform. Consistent with previous findings in vigilance tasks (Matthews et al., 2000; See et al., 1995; See et al., 1997) perceptual sensitivity in both vigils 1 and 2 declined over time and the participants became more cautious in responding as time on task progressed. However, neither of these outcomes was affected by the expected task durations that participants were given. Once again, temporal orientation did not affect vigilance performance. Apparently, the temporal context in which participants perform a vigilance task is not a factor in their performance efficiency.

Final elements to consider in the present study are findings related to cerebral hemodynamics. All previous studies involving task-related changes in CBFV using the transcranial Doppler procedure (see Shaw et al., 2009; Warm & Parasuraman, 2007; Warm, Parasuraman, et al., 2008; Warm et al., 2009) have shown than CBFV declines over time on task, a result that was duplicated in vigil 1 in the present study but not in vigil 2. The temporal decline in CBFV can be useful to the Air Force by indicating when an operator is in need of rest or replacement. However, prior to the present study, no assessment had been carried out to determine the time needed after vigilance performance for CBFV to recover to pre-task levels. Such an assessment could be of value to Air Force interests by indicating when an operator who is given a rest break is ready to return to the vigilance assignment. The results of the present study indicate that approximately 120 seconds are needed to stabilize the return of CBFV to pre-baseline levels. Of note is the finding that while CBFV had returned to baseline at the outset of vigil 2, its overall level in that vigil was less than that in vigil 1 and perceptual sensitivity in vigil 2 was also poorer than that in vigil 1.Consequently, it is apparent that CBFV return to baseline in and of itself is no guarantee that subsequent performance efficiency will be as effective as it was on an immediate prior vigilance assignment.

A key issue in the cerebral hemodynamics of vigilance performance is the hemispheric lateralization of bloodflow. Previous studies have demonstrated that the vigilance decrement is accompanied by temporal declines in CBFV which occur predominantly in the right hemisphere, a finding that is consistent with the viewpoint that a right-hemispheric system is involved in the functional control of vigilance (Langner & Eickhoff, 2012; Shaw et al., 2009; Parasuraman et al., 1998; Warm & Parasuraman, 2007). In accord with that view, was the finding in the present study that the superior level of perceptual sensitivity seen in vigil 1 in comparison to vigil 2 was

accompanied by a higher level of CBFV in the right than in the left cerebral hemisphere. However, contrary to the view of right hemisphere dominance in vigilance was the finding in the present study that the differential temporal courses of CBFV observed in vigil 1 and vigil 2 were similar in the right and left hemispheres. Previous vigilance studies with the CBFV measure by Hitchcock et al. (2003), Schnittger et al. (1997), and Schultz, Matthews, Warm, and Washburn (2009) have also found that the left hemisphere is involved in the vigilance decrement. Evidently, as Langner and Eickhoff (2012) have pointed out, there are a number of different brain systems involved in the regulation of vigilance and right hemisphere predominance is not always the case. As suggested by Hitchcock et al. (2003) and by Shaw et al. (2009), the right hemisphere may have primary responsibility for the overall level of performance efficiency but that both hemispheres play a role in the vigilance decrement. Such an account would be consistent with Hellige's (1993) point that even relatively simple tasks require the coordination of a number of information-processing sub-systems and with the view that a cooperative interaction model may best describe the mode of central functioning in regard to the vigilance decrement (Allen, 1983; Hoptman & Davidson, 1994; Warm, Schumsky, & Hawley, 1976).

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